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RoboCupRescue - Robot League
PHOENIX RESCUE TEAM, IRAN

Hatef Aria, Faramarz Arjomandi, Hadi Eftekhary, Farzad Houshmand, Arash Raeesi, Kasra Rezaee, Hossein Zibadel

Control & Robotic Lab., Mechanical Engineering Department, Faculty of Engineering, Campus #2
University of Tehran,
Kargar Shomali St. (Passed the Jalal-Al-Ahmad St., Across the Ninth Lane),
Tehran, Iran
rescuerobotics@engmail.ut.ac.ir

Abstract. This paper is to describe the activities done by some of the students of the University of Tehran to develop two mobile robots for participating in the rescue robot league of Osaka 2005 competitions; Phoenix and Squirrel. Phoenix is a mobile robot with tracked locomotion system which equipped with 4 arms to traverse different obstacles and is controlled semi-automatically, while squirrel is a mobile robot with simple tracked system for flat areas and is to be controlled automatically. We tried to state the performed activities and later programs also their goals and their capabilities. In introduction we first mentioned guidelines, and the complete and detailed discussions of each field are written in its specified section.

Introduction

Phoenix Rescue Team was established 18 months ago for the purpose of participating in Robocup rescue competitions. Robots were designed with respect to competition's conditions but a few changes are considered in designing the robot for real disaster application.

Two robots will participate in this competition as a team, called Phoenix and Squirrel. Phoenix is bigger in size, has 4 arms and has victim identification and navigation sensors. This robot will be responsible for map generation. The robot will be controlled semi-automatically. Squirrel is smaller in size and simpler in locomotion system and we are trying to control it automatically.

Squirrel will operate in nearly flat areas and it is designed to explore places which Phoenix won't be able to reach due to its dimensions. Using this robot will minimize the time of exploration.

We have used wireless LAN for communication because it can be developed and employed easily.

Manual controlling of Phoenix will be done by using keyboard and voice but some automatic behaviors are defined for the robot. Also in harmful or unstable conditions, the controlling system will send an alarm to the operator and/or make the proper decision itself. Squirrel is going to operate automatically but it can be controlled manually if needed. Robots' interface software is developed user friendly.

Map generation system is completely automatic and will create a 2D map with proper resolution.

For victim identification, several sensors and mechanisms are available, among which we have chosen thermal sensor, voice detector (microphone) and camera for motion detection.

For navigating the robots motor encoders, gyroscope, ultrasonic sensors and infra-red distance meter will be used.

From mechanical point of view, Phoenix is a mobile robot with high ability of traversing obstacles. It has four arms. Arms can rotate with respect to each other and the main body. They are also self-locked. There is also a mechanism for motions of camera and sensors deck. Squirrel has a simple tracked mechanism with a fixed camera.

Finally some video files are located at the address below for more comprehension. But it must be mentioned that some key parts such as main motors, control equipments etc. were not ready. Therefore, the robot was controlled with a cable and only the motion of the robot's arms was showed.

http://engmail.ut.ac.ir/robotic/index.htm

1. Team Members and Their Contribution

We are senior students of university of Tehran faculty of engineering department of mechanical engineering, electrical and computer engineering.

- Advisors:

1-Ha'eri Yazdi, Mohammad Reza: Associate Prof. Mechanical Engineering Department, University of Tehran.
Ph.D.: Robot Control, Imperial College, London, United Kingdom

2-Ghazavi, Seyed-Asadollah: Assistant Prof. Mechanical Engineering Department, University of Tehran.
Ph.D.: Dynamics and control of robots constructed out of composite materials, University of Renio, Nevada, U.S.A.

3- Navabi, Zainalabedin: Electrical and Computer Engineering Department, University of Tehran.
Ph.D.: HDL synthesis, Northeastern University, Boston, Massachusetts

- Team leader: Arash Raeesi

- Controller development:

  Hardware and sensors development: Mohammad Saleh Mounesan
  Kasra Rezaee (Operator)
  Negar Norouzi

  Software development: Hossein Zibadel

- Mechanical design:

  Locomotion system design: Faramarz Arjomandi
  Hadi Eftekhary

  Camera motion mechanisms: Hatef Aria (Operator)
  Farzad Houshmand

2. Operation Setup and Break Down

Two operators are assumed for controlling the robots in this competition but after final tests on the controlling system, using one operator for controlling the robots will be considered.

For carrying the equipments, a couple of packs made of light and firm composite material will be designed, in which every part of the equipment will be placed in its specified location. Each pack will be put in a knapsack and which is carried by the operators. Phoenix will be placed in one of the packs. Squirrel, electronic equipments and etc. will be placed on the other pack. The list of all equipments is mentioned at the end of this part.

After carrying the knapsacks to the site of competition, operators will unload them, transfer the robots at the entrance of the zone and set up other equipments on the table. They will turn on the robots and computers. The total time needed for unloading robots and equipments, switching them on and the establishment of WLAN connection would be less than 10 minutes.

It must be mentioned that for transferring Phoenix in long distances, the robot will be disassembled into 5 parts (4 arms and the main body) in order to use smaller packs and increase the safety of the transfer operation.

Finally, our equipments are as follows:

1- Phoenix mobile robot
2- Squirrel mobile robot
3- 2 laptops
4- A small printer

And there are some optional equipments which are especially used for the case of real disaster:

1- A tool box for fixing the robot
2- 2 X-chairs

3. Communication

To establish a 32-bit wireless network, a computer is considered as the server and by installing small industrial computers with low power consumption on the robots sufficient equipments for wireless net working are prepared. Three 802.11a (5GHZ) wireless devices are have been installed on the systems, one on the operator's computer and one on each of the robots.

We use a 3Com® 802.11a wireless PCI adapter with maximum sensitivity of 54Mbps at -70dBm and minimum 6Mbps at -87dBm, and frequency band of 5.150 GHz and 5.825 GHz, with transmitting power of 16dBm (40mW), which operates in temperature between 0°C up to 50°C.

Fig. 1. 802.11 a (5GHz) wireless LAN

It should be noted that the connection No.1 (i.e. between the server and client) is permanent but the connection No.2 (i.e. direct connection between robots) is not presented and only switched on in specific condition by the command of server.

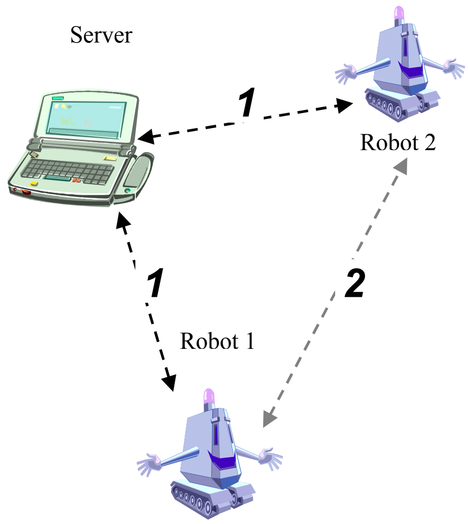


Fig. 2. Communication between robots and the server

All the data is transmitting in the network are compressed. So the required data is received and sent via a custom protocol in the shortest time. Exact and proper selection of hardware and design of software will lead to the capability of controlling the robots from distances as far as almost 80 meters. For a longer communication the switch-on command of the connection No.2 is sent from the server so that each robot will become the server of the next one. For this purpose the software construct an array of robots with respect to their distance from server. These actions are done automatically and very fast by the central computer. Therefore with respect to the number of robots, an extended area will be undercover for the connection.

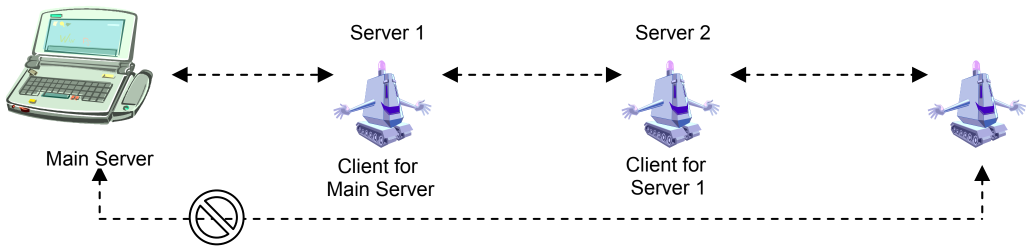


Fig. 3. Each robot can operate as the server of the next one

Design of the interface software with respect to the properties of the Microsoft Windows provides the capability of controlling 8 robots manually and semi automatically.

The maximum amount of data that can be transmitted in every 0.1second is 24576000 bits. 225 out of this 300 Kbytes is for transmitting the main camera's images. 2 block of 35 KB for 2 other cameras, about 5KB for microphone and 256 Bytes for sensors and other systems is considered.

The amount of data which is received from the server is comparably less than the one that is sent. It is about 128 bits in every 0.01 of seconds which consists of information like motion orders, arms rotation orders, controlling and transmission of the camera and sensor deck and turning on and off the lights.

To make sure the communication is working properly a ping is sent to the robot continuously and in response, the robot sends another ping to the server which means the communication is established properly.

Table 1. Wireless communications frequencies

Rescue Robot League Competition Osaka Japan		
Phoenix RT (Iran)		
Frequency	**Channel/Band**	**Power (mW)**
5.0 GHz – 802.11a	5.150 GHz	40 mW
5.0 GHz – 802.11a	5.825 GHz	40 mW

4. Control

4.1 Phoenix Robot:

Phoenix is controlled in a semi-automatically manner. Controlling various parts of this robot is divided into two modes, the manual mode and the automatic mode. In manual mode the operator has full authority on the all parts of robot and the robot is controlled, trough the operator's orders. This mode of operation has the highest priority, and the operator can handle all parts of robot whenever he/she feels it's needed.

Semi-automatic mode is used in special conditions and the locations which are pre expected, in order to help the operator, and to improve the robot's control. In cases which the situation has been anticipated before, operator specifies the pre expected situation and commands the robot to operate in that situation, then the software takes the required information from the sensors and operator. And the software controls the robot completely. For example when the robot encounters steps the operator orders the **step**, then specifications of the step are received through the sensors and then the software controls the robot to climb the steps. It must also be stated that in this control mode, the operator can control the motion of the robot whenever he/she feels it is necessary.

An automatic error correction system is also considered for the robot, which can be activated or deactivated. A part of this system is installed in robot's drivers and the other parts are considered in the software development. The part that is located in the robot is for preventing the hardware faults such as asynchronism in the main motor's rotation or errors in the arms' motor. The parts that located in the user interface software are considered due to operator's faults, such as obstacles which the robot encounters and are out of operator sight or when there is probability that the robot to become overturned.

Whenever the system is enabled for correcting the error, it eliminates the error. And when the fault is inevitable the system operates such that to prevent robot from damages (For example this system can command the robot to retract camera and sensors deck inside the body when there is the risk of robot overturning of robot or stop the robot when there is a hole).

To facilitate the control of all parts by computer we have considered a PCI I/O card. This I/O card can simply be assembled on the main board. It provides 16 digital input/output terminals, 16 analog input terminals and 2 analog output terminals which are sufficient for controlling all parts of the Phoenix robot. Obviously by this card some parts of intermediate circuits are eliminated and more I/Os are available with considerably more speed.

The computer which installed on the robot is only applied for an interface between robot and the operator. This computer receives order from the operator's computer- through the wireless LAN- and also sends the sensors data and cameras images to the operator's computer. It can also perform some initial processes on the raw data, coming from cameras and sensors for a faster function, if needed.

The data of commands generated in the operator computer (by the direct order of operator in manual mode or by a pre-organized procedure in automatic mode) is sent to the Phoenix computer via the wireless LAN. The computer of Phoenix performs the necessary processes on the data and generates the required signals for drives. Through the I/O card, these signals are applied to the drives and the drives run the motors. At the same time the sensors' data (in the raw format) are collected by I/O card and the valuable part of these data is filtered. Also the data of cameras are collected by the capture card. Then the sensors' data and camera's data sends to the operator computer via the wireless LAN. These data will be presented for the operator and decisions will be made in operator's computer (in an automatic manner or by the order of operator).

4.1.1. Main Motors Controlling System

Control system of the main motors is designed so that the motors can operate in variable speeds. This system is used to gain faster and more efficient motion. High speeds are used in open areas without many obstacles and in the cases which the highest power is needed (for climbing obstacles). But in critical cases we use low speeds for higher accuracy. A PWM method is used to control the speed of motors [6]. In this method a proper voltage is applied to the motors in the form of rectangular pulses with the frequency of 10 kHz. We can change the transmitted power to the motor by increasing or decreasing the length of pulse. Since the motor is working in nominal voltage, this method will not affect on motors efficiency.

The encoders installed on the motors to help us to find the asynchronism faults in the rotation of motors. Then by using a closed loop negative feedback we can synchronize the rotation speed of motors. By exerting specific angular speed to each motor we can get the desired motion of robot such as straight motion, turning and spinning.

4.1.2. Controlling the Rotation of the Arms

There will be an encoder, installed on each arm to verify the position of them with respect to the robot’s main body. Each encoder consists of a circle with dark and light areas which is coupled to the arm, and an infrared sensor adjusted next to each circle, this sensor detects motion of the circle, which means rotation of the arm. This system is also applied to synchronize the arms whenever needed. For a better operation there is a reset sensor installed on each arm which detects the horizontal position of arms and resets the data of encoders. This sensor prevents increasing effect of the errors.

4.1.3. Controlling the Camera Deck

The robot’s main camera (robot's eye) has the ability to be controlled from the central computer and is used as a path finder and victim identifier unit. Two other cameras are fixed and installed in front and in the rear of the robot these cameras are used to have direct access to the path of robot and also the state of the arms. In addition they can be used when we are forced to retract the main camera. All the cameras have the minimum precision of 10 FPS. The main camera is controlled in two ways; Manual control, or the automatic control in which the operator specifies a coordination in one of the two optional coordinates (spherical or Cartesian coordinates) in case of using the 4 DOF manipulator in user interface software with respect to camera’s primary state, then the software automatically controls the motion of camera to the specified point (in case of using 4 DOF manipulator). To achieve this goal we used stepper motors so that, the exact position of camera in every motion is known. Due to time length of operation, increasing errors may occur and lead to big faults. So we used a base point reset that resets the position of camera every time the camera reaches there. Also the operator can reset the camera control system. So that the camera deck come back to a specified point (base point).

Software named T VIDEO GRABBER and is used for sending frames of camera images via the wireless network, which leads to a more efficient and faster image processing on operator's computer.

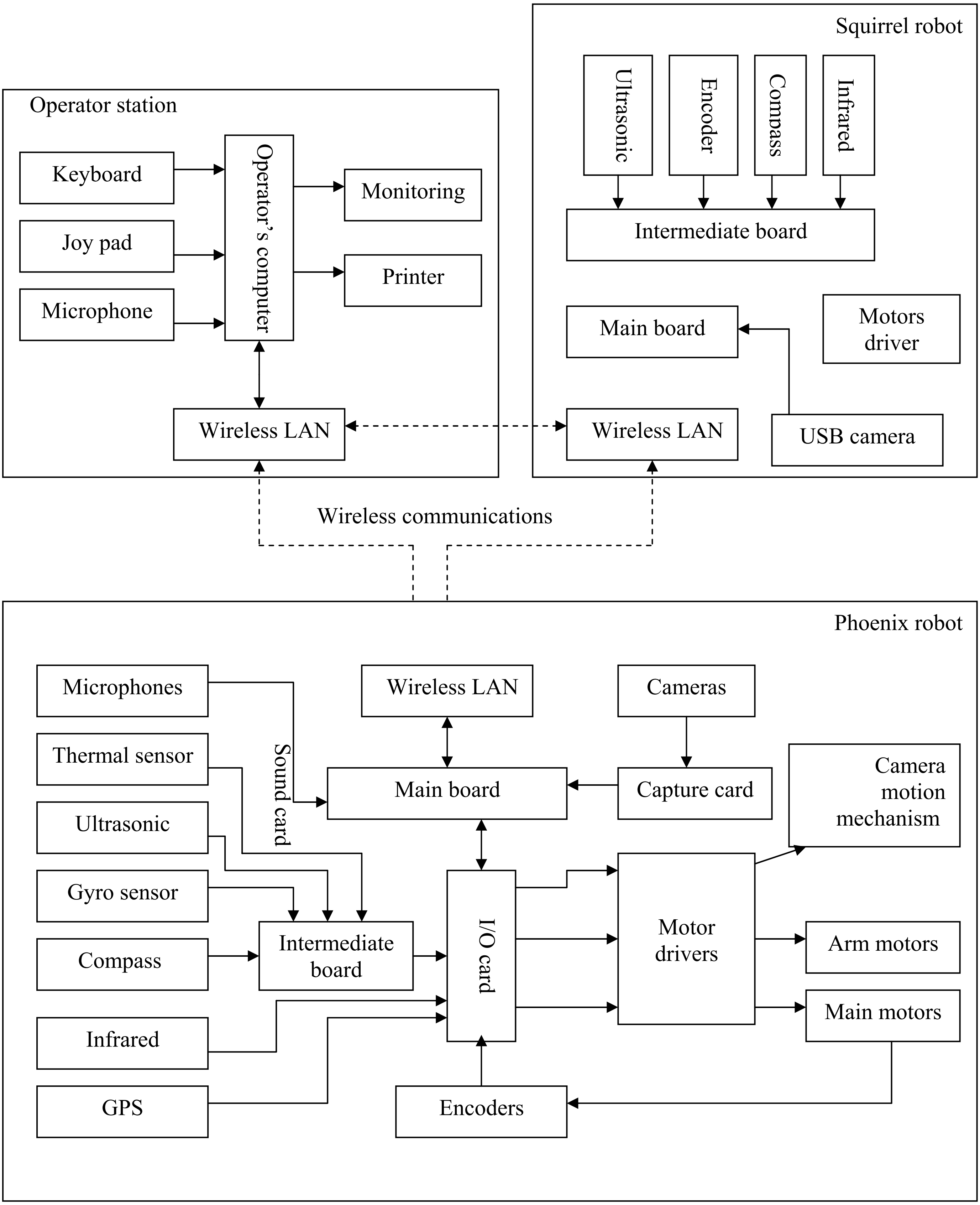
If the robot exits controlling domain such that the establishment of communication is impossible, robot takes its control and start to go back along the traveled path till the communication establishment will be possible again.

4.2 Squirrel Robot

The Squirrel is used only in flat areas and its function is to accelerate the exploration. This robot is going to operate full automatically**.** And in case of identifying a victim it reports its location to the operator's computer. But it will stop in case of any fault, and then the operator will control the robot manually. Also operator can switch the robot into manual control, whenever it is needed.

The automatic control of robot is performed by the operator's computer. Whenever it’s activated, the robot's computer collects data from sensors and sends them to the operator’s computer via the wireless LAN. The software processes these data and makes appropriate decisions to control the robot. By considering that the operator’s computer knows the position of Phoenix and where it has searched, it can control squirrel to search within places where the phoenix has not searched yet, due to its dimensions. This robot operates specially near the walls and corners. And whenever the software feels that the robot is going far away from the walls (by using ultrasonic and infrared sensors) or going toward steps or holes, the direction of robot will be changed. Also if software feels that the situation is critical or can’t find any solution for the motion, it stops the robot and warns the operator about robot’s situation. There is a camera installed on this robot, which the screen of this camera will be presented in operator’s computer in every moment. When the robot stopped, operator by using the camera controls the robot manually and when the risk of damage disappeared, the controlling system will be switched into automatically. Also there will encoders installed on the robot to detect the motion of the robot and to locate it. The resetting system of this robot is manual, and operator assigns the position of robot manually by taking it to a known place (where the phoenix generated map for it previously) and fixes the position of the robot (this place is recognized by using the camera). There are some sensors for victim identification on this robot, and when the robot finds a victim alarms the operator and stop. Then the robot will confirm the existence of the victim by using a camera in the map by using the robot's position.

Control Block Diagram



4.3 User Interface Software:

It was decided to develop this software with Borland Delphi 7.0. This software provides the whole robot information of the robots and camera screen in one window.

The software provides the ability of controlling the robot in 2 different methods: by using keyboard and by joystick (up to 2 or 3 joystick can be used simultaneously). In addition we have an idea for a combined control method with voice command and one of those instruments mentioned above. Obviously this combined control method is more effective and easier. For example robot's motion can be controlled by keyboard or joystick and motion of camera and sensors deck can be controlled by operator's voice; anyhow the case of voice-keyboard is more desirable for us. We are going to use speech recognizer software to achieve the capability of voice command control method. Experiments in voice command detection shows that it has less than 10% of error. Also this method can be developed for more than one operator.

5. Map Generation/Printing

For generating a 2D map of the surrounding area and specifying location of the robots and traveled path we equipped the robots with these instruments:

1. Ultrasonic distance measurement sensors
2. Two Encoders installed on main motors in order to count the rotations of 2 main motors.
3. One Analog Compass with precision of 1°.
4. One gyro sensor with 2 channels for determining robot's main body state with respect to the horizontal axes (only on Phoenix robot).

Note: All the outputs of the above equipments are sent to the main computer in every 0.1 seconds.

By knowing the traversed path of the robot we can have the victim's location, which were identified during the exploration mission. In addition to by generating the surrounding area map the rescuers can operate by an awareness of surrounding area.

5.1. Localization and Traversed Path Determination

For calculating the direction and the length of the movement a compass and 2 encoders are used.

The main camera is also used along with these equipments for achieving a better result.

Also after selection & installation of these equipments, a 2D screen in the computer with 1024x * 1024y pixels have been imagined. Every pixel in this map is almost equal to 10 cm in the reality. The robot will be assumed in 1024/2, 1024/2 position (an optional fixed point) in order to have no negative numbers.

For calculating the length of motion, 2 encoders are used .So that every 185 rotations of the motors, robot will move almost 20cm forward.

The only problem that may occur is in the case that the robot stocks and doesn't move but the main motors rotates properly as before; in this case the output of the ultrasonic sensors to will be compared with encoders data make sure of the movement, if the robots doesn't move these sensors give constant numbers so the data from encoders won't be read (that means the slippage of tracks). Also it can be checked for it by comparing the receiving frame of camera and check if any changes happened.

The advantage of this system of localization and path generation is that more simple equipments with lower cost are used.

From algebraic summation of the outputs of the encoders and the compass, the position of the robot in the map with (x, y) coordination and the polar angle of main body (with respect to the North Pole) will be determined.

Then these points will be put together. These lines will show the path, which the robot explored in the user interface software.

If the robot stops right next to a victim and detect a victim, the computer marks this coordination of the robot in the map as a victim.

When the robot traverses ramps or steps, the gyro sensor is used to determine the height of the spot in which the robot is located with respect to the start point.

So far the local position of the robot with respect to a fixed point (start point) is known. By using a GPS system it will be possible to determine the global position of the starting point and calculate the global position of the robot in each moment.

5.2. Map Generation

The responsibility of generating environmental map is considered only for the Phoenix robot.

The environmental map is generated by means of ultrasonic sensors. 5 ultrasonic with an angle of view of 15° in different places, one in front of the robot , 2 on the sensors deck and 2 on sides of main body (specially for detecting walls in mazes for a fully 2D map) are installed.

The two sensors placed on the deck are located on a vertical line. Due to the angle of view 15° of ultrasonic sensors and distance from the nearest obstacle, an almost wide range of points on a vertical line on the nearest obstacle is approximated with two points. In this method if the measured distances differ less than 15% in their values they would be considered as a unique surface with the average distance. But if the values differ more that 15% the values will be considered separately as two surfaces with different distances from robot. But in this method the robot shouldn't be located so far from the corresponding obstacle because the measured points are not close enough. With the robots motion the map is generated autonomously (in every 0.1 of seconds a new point, is generated with respect to speed of changing data).

By the method mentioned above we attain a 2D map which can be extended in the normal direction and presented as a 3D map, also when the robot passes ramps or steps etc. the map should be presented in a 3D state.

Some objects like Walls, tables etc can be known almost by the frames, which come from the main camera. The sensors can almost identify these objects, and consequently the computer alarms the user that there are some sort of objects close to the robot. (It can be anything).Then a window will be opened automatically and show some predefined objects (i.e. Wall, table, door …) in different sizes in order to the type of the obstacle be selected , after selection the type of obstacle or object that the computer marks that place as an object and names it.

At the end of mission the generated map and data sheet of each victim will be printed and submitted.

6. Sensors for Navigation and Localization

The main point in controlling the robots is to know the exact position of them. To achieve this goal a base point to will be chosen the robot's base position, and from there the transmission of robot will be determined. To determine the transmission of robots we decided to use several sensors and combine these sensors data for a complete navigation and localization.

6.1 Direction

6.1.1 Compass

We used a compass to detect the direction of the robot with respect to the North Pole.

This sensor is a hall-effect sensor which has two outputs in a sine-cosine set of curves. If the sensor displaced, the analog output will change. In an intermediate circuit (between sensor and computer), first these signals will be amplified and then they will be digitalized and sent to the robot's computer through I/O card. Then by taking a base point for the direction, signals will be processed and the direction of robot will be determined in the robot's computer.

Fig.4. Analog compass

6.1.2. Gyro sensor

When the robot is climbing a ramp or steps, the angle of ramp is needed to determine the transmission of robot with respect to the horizontal axis. A gyro sensor [7] is used to determine the angle of the main body of robot with respect to the horizon.

This sensor is a piezoelectric sensor which detects speed of rotation, and then sends out an analog voltage which is about 0.67mV/deg/sec. In this case by taking a base angle for robot's main body, the angle of the main body will be determined with respect to horizon moment by moment.

Fig.5. gyro sensor

Another gyro sensor is installed in a perpendicular direction with respect to the first one, in order to detect the angle of robot with another axis. This sensor is specially used for determining the stability of robot in order to help the operator automatically when the robot may upturn.

This sensor is only used in Phoenix robot because Squirrel is used only in simpler areas.

6.2. Movement

6.2.1. Motor Encoders

These encoders are installed on main motors to report rotations of motors with 1 pulse per degree precision. The motor is also coupled to wheels and the rotation of motors lead to rotation of the wheels. Therefore by counting pulses of the encoder linear transmission of robot is determined.

6.2.2. Ultrasound

Due to slippage of wheels, another way for determination of the robot's motion is needed in order to attain a higher accuracy. The method is to use ultrasonic distance meters which is placed in the front of robot. In case of straight motion the closing rate of the objects in front of the robot is the robots speed. By combining the result with the encoders, we can determine the exact transmission of robot.

Fig.6. A set of ultrasonic and infrared distant measurement sensors

We have used 40 kHz ultrasonic transmitters and receivers. The drivers of the sensor have been designed and completed. A 40 kHz signal with a serial code (to prevent from cross talking between other sensors) is transmitted and the reflection of this is received. With calculation the time of wave radiation will be determined distance from nearest object. Importance of this circuit is that it has two sensitivities; low sensitivity is used for short distances and high sensitivity for long distances. Therefore the ultrasonic sensors won't have no dead zone and blinded area and they can determine distances from 1cm up to 3m.

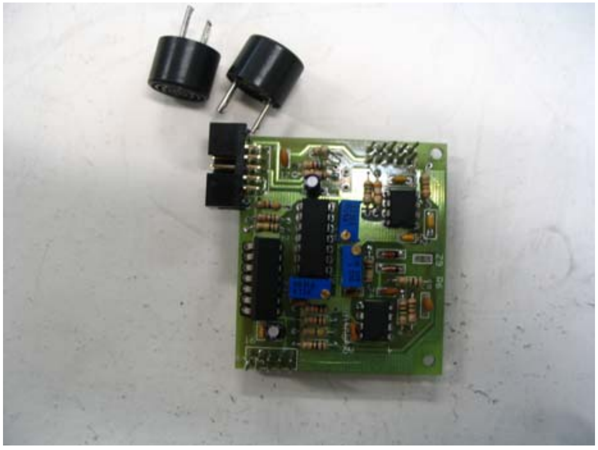


Fig.7. proper circuit for amplifying the output of infrared and ultrasonic sensors

The ultrasonic sensors are also used for map generation system as it mentioned.

6.2.3. GPS

A GPS system is going to implement for global positioning on the phoenix robot. Accuracy of this GPS is about 1 meter and it's not a very acceptable way to localize the phoenix robot. But it is a good way to prevent large faults in the localization. If the position detected by sensors differs considerably from the GPS system, the position will be corrected by the data of GPS system.

6.2.4. Infrared

There are some low range infrared sensors for detecting objects near robot. These sensors detect objects in distances of about 1cm to 10cm. These sensors are used on both robots. In Phoenix this property is set to use to help operator when there is an object near the robot or in its path which is out of the operator's sight. In Squirrel robot this property is for detecting walls, holes and also any other objects that may make trouble in the motion of Squirrel.

6.2.5. Cameras

The main vision equipment for Phoenix is a camera which is installed on sensors deck. This camera is the main camera for navigation of robot.

Due to the motion limitations of main camera, and the places which are needed to be seen frequently, 2 cameras were installed in the front and at the rear of robot. Also these cameras are used to have direct access of the path of the robot and also to show the state of the arms.

7. Sensors for Victim Identification

7.1. Temperature

An infrared noncontact sensor [7] is installed on the sensors deck to give full information about the temperature of surrounding objects. This sensor receives the infra-red radiation which is enlightened from objects located in a cone with an eye vision of approximately 15 degrees, and gives out the average temperature of this measurement as the output as an analog voltage signal. This sensor measures the temperature between -20 and 100 degrees of centigrade accurately. An intermediate circuit was used to rescale the output signals to rescale the output signal of sensor for human body temperature. This function will result in simpler processes and more accuracy in measurement. The scaled output goes to robot's computer through the analog input of an I/O card, and the robot's computer sends the data to the operator's computer. The sensor's data is checked automatically, and by changing the sight of sensor, any difference in temperature will be detected. By comparing the data approaching to the victim will be alarmed. Also, with respect to the sight of sensor, when the robot finds a victim, the sensor can determine the victim's body temperature by approaching him/her up to 1 meter.

7.2. Voice Detector (microphone)

The purpose of using a microphone is to find the victims who have been buried under the rubbles and their bodies are not easily detectable by the operator, using video screens.

Therefore two microphones are placed on each side of the robot, which receives environmental sounds. A filtering system that can be activated or deactivated processes the sounds in order to remove the sounds that are out of frequency range of a human being's larynx. The operator is able to listen to the resulted data and to identify the victim.

We are trying to develop an intelligent program applied to compare the features of the sound data receives, with some predefined features of a victim sound, and if the features match; the operator will be alarmed of an existing victim.

7.3. Image Processing

Another secondary program is image processing which is applied to help the operator find the victim. This program operates in two ways.

7.3.1. Motion Detection

By comparing two consecutive frames of camera, any region of the camera screen in which any motion happens could be detected .This feature operates automatically when robot is stopped.

7.3.2. Color Identification

In the world of digital colors by combination of 3 main colors which are Red, Green and blue we can have almost any color we want. In computers the main colors are divided in to 255 small pieces. A spectrum of colors between 0 to 255, will fills a byte. In this structure of color 0 is the darkest color and 255 is lightest color. For example by calling a color as (R=255, G=0, B=0) it is going to show a pure red.
This method will be used to analyze the colors to mark the victim's uniforms.

First of all a single frame from the main camera will be gotten. The image will be separated pixel by pixel to know every pixel's color. By calling a function which is shown below, the structure of color will be determined, this function tells us how many red, green and blue pixels are in image.

```
Function Color_Analyzer(Color : Cardinal; Var Red, Green,
Blue : Byte) : String;
Begin
  Red := Windows.GetRValue(Color);
  Green := Windows.GetGValue(Color);
  Blue := Windows.GetBValue(Color);
  IF (Red > Green) And (Red > Blue) Then
  Begin
    Result := 'Red';
  End;
  IF (Green > Red) And (Green > Blue) Then
  Begin
    Result := 'Green';
  End;
  IF (Blue > Red) And (Blue > Green) Then
  Begin
    Result := 'Blue';
  End;
  ...........
  ...........
  ...........
End;
```

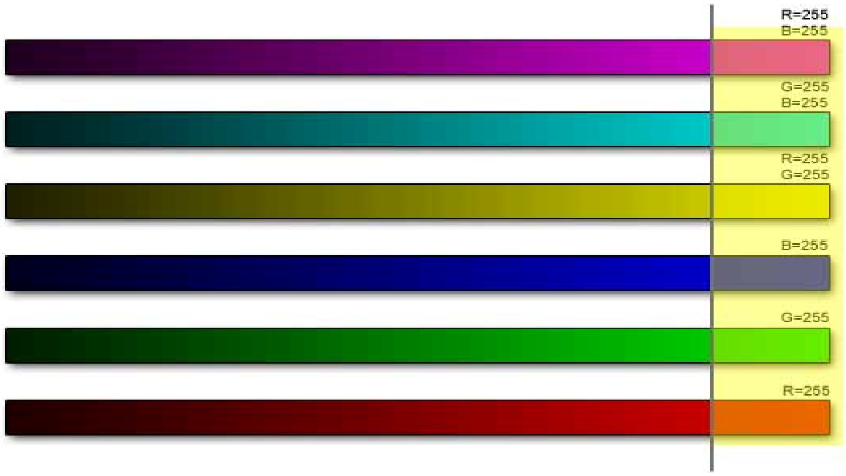


Fig. 8. Colors spectrum

If the value of a variables gives a number larger than 200 as shown in the figure (marked as yellow area) then the function starts to grab all the pixels around that pixel by a tolerance of +32 and -32 which are the colors near the main color. By grabbing all these pixels we can almost determine that how big is that area and estimate the probability of victim existence. All these tasks are down in almost 0.3 second that means by activating the color identification function on the user interface software to recognize probable victims; the camera display operates slower up to almost 3 frames per second.

Note: This method of victim identification runs in the main computer so there will be no interruption in the robot's function.

Fig. 9. Image before process

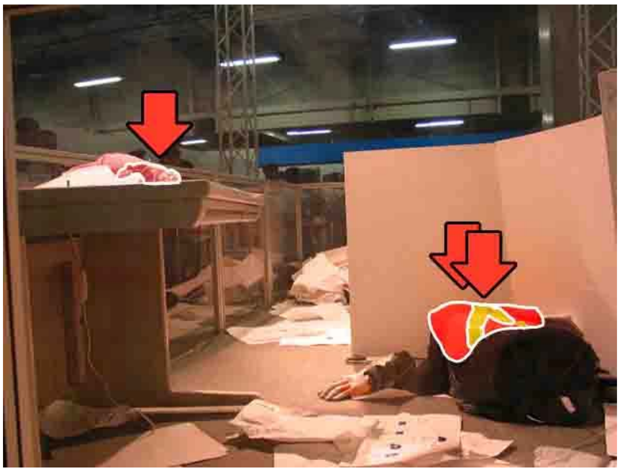


Fig. 10. Image after process

8. Robot Locomotion

The description of robots locomotion will be divided into 2 parts: Phoenix & squirrel:

8.1. Phoenix

With respect to the advantages of tracked systems such as high tractive force, no road preparation and ability to turn round a point within the robot, this system of locomotion was selected for this robot. [1]

By defining a "**standard obstacles table**"[1] and analyzing different methods for traversing these obstacles, the 4 arms system was chosen for this robot.

This is a robot with a main body, main crawlers (belts) at the sides of the body and 4 arms with crawlers at the corners of robot.

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[1] See appendix.1

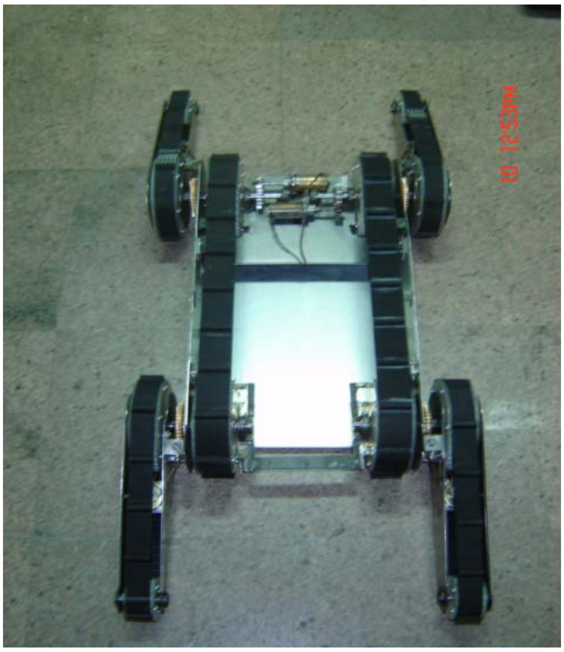
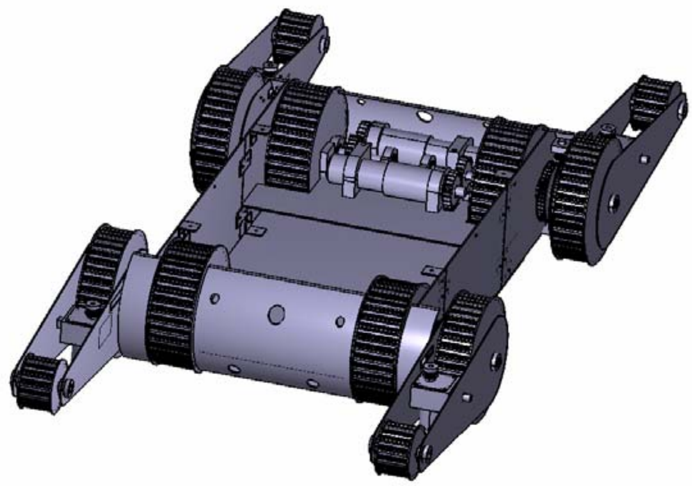



Fig. 11, 12. Phoenix's general view

To attain more capabilities due to the real disaster sites and also competition situation, we've considered the features listed below in the design process.

1- The arms are placed outside of the robot, so we can use the space inside more effectively, design more simple system for rotating the arms and also make the robot be more stable while it is standing on its arms.
2- Main crawlers are at the sides of the body. Therefore, motion, turning and spinning will become easier [1].
3- Minimizing the height of the robot so that it can explore under the obstacles and also to decline the height of the center of gravity in order to gain more stability.
4- Main timing belts are turned round the main body so this tracked system doesn't need any idler for tracks.

8.1.1. Locomotion:

There are 2 arms and a main crawler on each side of the robot. The rotation of the timing belts of all the three is done by one motor that will cause the even linear speeds of all three tracks of each side. Also using one motor in each side reduces the number of motors needed for robots locomotion. We are using two 70 watt DC motor with gear-heads from Maxon Co[2].

There is a motor in each arm so the arms can rotate independently with respect to each other and to the main body. Placing a motor in each arm has divided the weight

[2] See Maxon motor products catalog, pages 81,218,233

of robot in the arms and increases the efficiency of them. The power of motor is transmitted to the worm by using a timing belt. The worm is connected to the arm and is engaged to a gear which is fixed to the main body. The rotation of worm causes the rotation of arm around the axis of gear. Using worm-gear mechanism have advantages such as being self-locked and also increasing the torque of the motor to gain the sufficient torque for rotating the arm.

(Related video file: http://engmail.ut.ac.ir/robotic/worm-gearing.wmv)

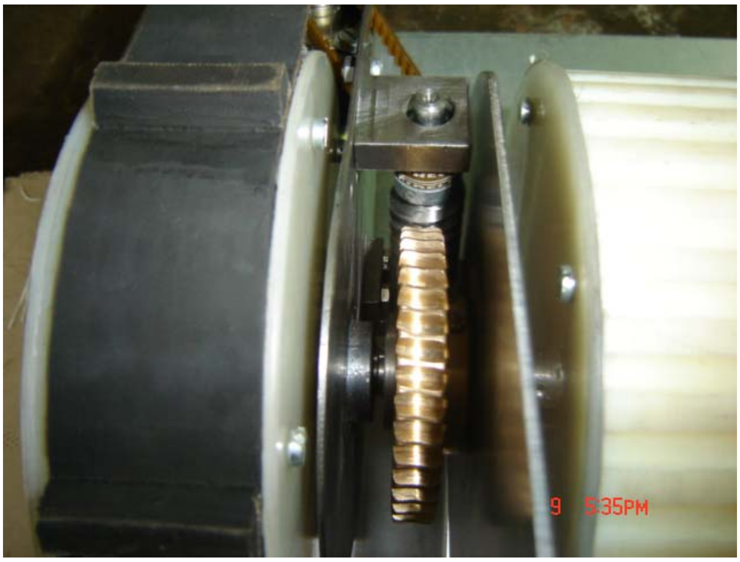


Fig. 13. The worm and the gear engagement

Fig. 14. The power of motor will be exerted to the worm by using timing belt

The rear pulley of each arm is connected to the shaft of main body pulleys but front pulley can rotate freely. Therefore, if the arm rotates when the robot is moving, rotation of this pulley will be self-adjusted so the arm's rotation will be done properly. This system is similar to a planetary gear train in which the sun rotates and the arm rotates with respect to the sun simultaneously [8].

In this tracked system, positive drive timing belts, H serie (p=1/2) with width of 2" for main timing belts and 1.5" for arms' timing belts are used. Strips of V-belt have been attached on the outside surface of the belts to make them cogged and also increase the friction in the straight direction while friction in normal direction is not affected considerably. Also these teeth will engage the unevennesses of the ground and make the locomotion easier.

Fig. 15. Timing belt

Pulleys are made from polymer that was designed with respect to the timing belts. The pulleys of the main body and rear pulleys of the arms have an approximate pitch diameter of 154 mm. and the front pulleys of the arms have an approximate pitch diameter of 65 mm.

8.1.2. Arms Position in Different Situations:

a-Flat grounds: The arms' tracks do not touch the ground. Arms are retracted to the sides of the body as tight as possible in order to minimize the height and length of the robot.

Fig. 16. The arms are retracted

b-Rubbles: Arms won't be expanded on the ground but they will be extracted in order to be stretched on the ground as fast as necessary.

Fig. 17. Arms are extracted but not expanded on the ground

c- Steps: when the robot reaches the proper distance from the steps. Front arms start to rotate until they reach the first step and rear arms are still on the ground. By rotation of the front arms, the body will stand parallel to the front arms. The rear arms will push the robot a little forward. Then the rear arms will rotate until they'll become parallel with other parts and the robot will move along the steps.

Fig. 18, 19, 20. The procedure of passing steps.

d-Relatively high obstacles (up to 40 cm.): the center of gravity of the robot is placed so that the robot would be able to raise one of its front arms while it is standing on the other three. With respect to this ability, the robot can rotate one of the front arms and put it on the obstacle while it is standing on the remaining three. Then the other front arm will rotate and will be placed beside the other. These two arms will lift the body up to the obstacle

Related video files: http://engmail.ut.ac.ir/robotic/ST1.wmv
http://engmail.ut.ac.ir/robotic/ST2.wmv

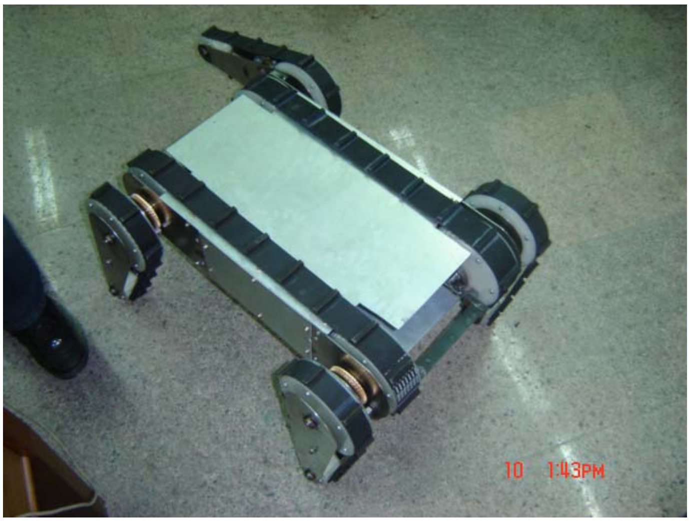


Fig. 21, 22. Phoenix can stand on 3 legs.

8.1.3. Main Body

Wheels are placed so that they are the first part of the robot that will contact an obstacle. This will avoid the main body to contact the obstacles. For obstacles with less width, two curved metal part are placed in front and rear of the body. The equipments and parts of the front side and the back side of the robot are grouped and assembled separately in order to facilitate the assembly and then these parts will be joined together by the main body.

Dimensions:

Length with retracted arms: 630mm.
Length with expanded arms: 1110mm.
Width: 520mm.
Height: 160mm.

Weight: 17-22Kg

Speed: 31cm/s

8.2. Squirrel

Because of the main advantages of tracked system mentioned above, the tracked system was selected for squirrel's locomotion too. According to the determined applications for the squirrel[3], it was considered a small and more simple robot with a body placed between the crawlers completely. In contact with obstacles, it will be the crawler which will touch the obstacles first so the body won't be in touch with the obstacle.

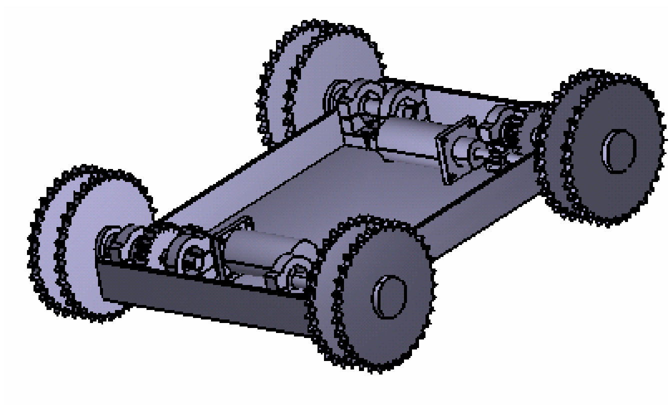
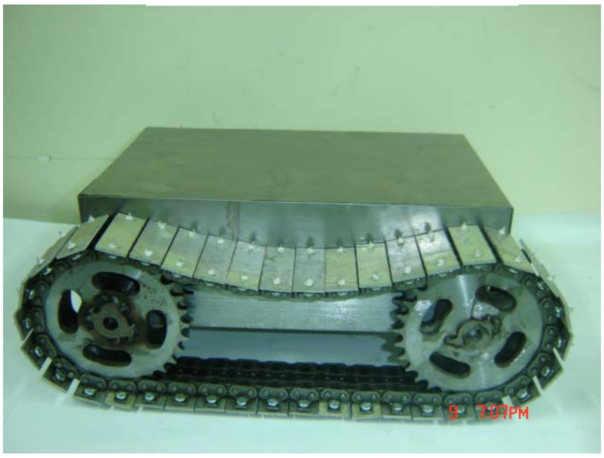


Fig. 23, 24, 25. Squirrel robot



[3] Which were mentioned in the introduction

The pulley and timing belt system was used for the Phoenix while sprocket and roller chain were tried for the Squirrel to get familiar with designing and related calculations. Each wheel of the robot contains 2 parallel sprockets welded to a bearing and the bearing is connected to a shaft and this shaft rotates by the exerting torque of motor trough a set of gears. Two roller chains with short pitch conveyor attachments will rotate around the sprockets in each side. A small strip of aluminum sheet is bolted to parallel attachments of the rolling chain that make the 2 rolling chains move together and also play the role of crawler for the robot.

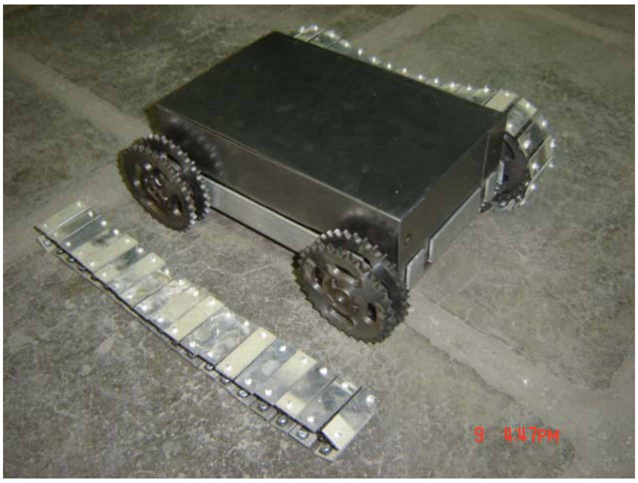


Fig. 26. The chain plays the roll of crawler.

As it can be seen in figure 23, motors are located crossed and the torque of the motors will be exerted to the sprockets by using a set of gears on each motor.

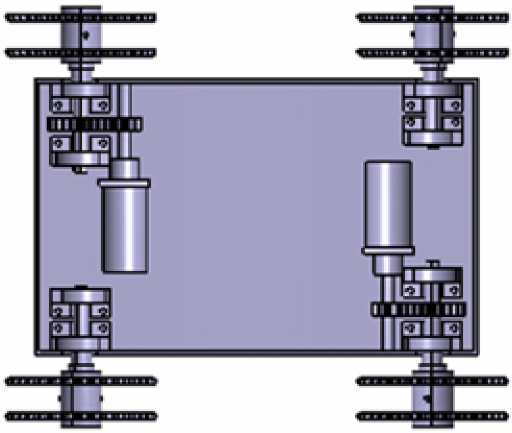


Fig. 27. Motors are located crossed

Roller chain and sprocket system has all the abilities of timing belt and pulley system. The main disadvantage of this system is that the robot would be heavier because the sprockets and the rolling chains are made of metal. However, it must be noted that the distribution of the weight is still symmetric and will not suffer robots stability.

Another disadvantage of this system is that in a critical speed, the rolling chain and the sprocket will be locked together [4], but calculations have proved that this robot won't reach the critical speed of rolling chains and sprockets used in it.

Dimensions:

Length: 365mm.
Width: 304mm.
Height: 102mm.

Weight: 6-7Kg.

Speed: 45cm/s

9. Other Mechanisms

Another important mechanism that is required on the system is a mechanism to move the deck on which the main camera and some of sensors and detectors are placed. We have introduced two different mechanisms for this purpose.

9.1. Telescopic mechanism

In this mechanism, 5 frames made of metal rods (in which the largest one's size will be 12*12*12 cm and the others which are smaller than the first one) are placed inside each other and connected with two symmetrical crossed strings. When the DC motor rotates with 20 r.p.m, strings circulate around two pulleys and the frames will rise with a linear velocity of 5cm/s. It should be noted that care is taken so that rise is in order of their size. By rotating the motor in the opposite direction, strings are released and the frames will come down due to their weight. This system can rise up to 60 cm. There are two driving step-motors for moving the deck, one for determining the camera's orientation with respect to the horizontal axis which gives the ability of covering the range between -45 and +45 degrees and another step-motor is for turning the deck 360 degrees which forces the system to have 3 DOF.

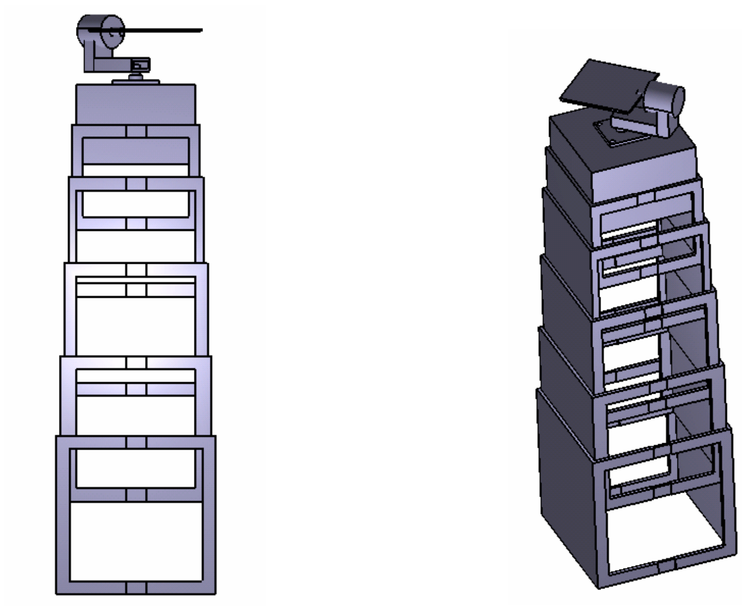


Fig. 28. Telescopic mechanism

Advantages of this system are as follows: 1- It is possible to retract the system completely inside the robot. This will allow the robot to continue its duty in case of being upside-down. 2- It is possible to raise the height of the deck as much as needed by adding the number of frames.

9.2. A 4 DOF mechanism

This mechanism consists of 2 arms, 4 step-motors and the deck. The deck is connected to the shaft of a motor that allows the deck to rotate 360 degrees; this motor is fixed on a holder which is welded to the end of the second arm. The arms are made of rectangular hollow section aluminum rod. The length of second arm is 35cm and the first is 25cm long. The arms are connected in the same way that was mentioned above. The first arm is connected to the shaft of another motor. This motor is bolted to a metal sheet. The whole mechanism will turn by a step motor which is placed under the sheet. Step-motors can be precisely and easily controlled, so they are the most proper choices due to special need of precision in this mechanism.

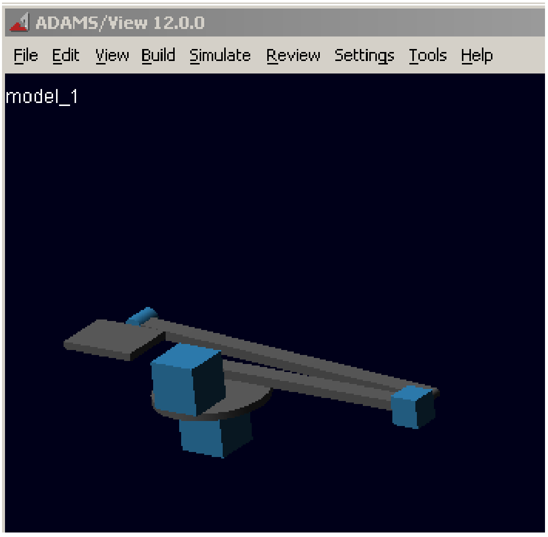
The advantages of this system are:

1- The deck and the second arm are able to turn 360 degrees. The other arm can turn 180 degrees.

2- This mechanism is able to reach any point in space within a semi-sphere with radius of 60 cm.

3- By using this mechanism, operator is able to see the robot itself and also beneath the robot.

Related video files: http://engmail.ut.ac.ir/robotic/4_DOF.avi
http://engmail.ut.ac.ir/robotic/4_DOF(with%20diagram).avi



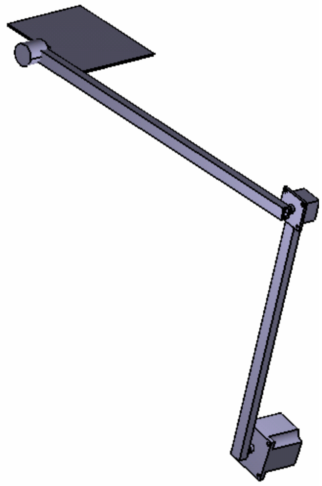


Fig. 29, 30. The 4 DOF mechanisms

Both of these mechanisms have advantages and disadvantages. By using the first we will have the ability to move upside-down because the mechanism will retract completely inside the robot. In case of using the second one, the camera deck can move in any direction and this will afford an extra potential for victim identification. Therefore, by considering all aspects of these two mechanisms, the final decision will be made.

10. Team Training for Operations (Human Factors)

It was mentioned before that we prefer a keyboard for controlling the robots. Also a conditional system of voice control is added to ease the function of the operator.

Generally two operators are considered for competition. One for driving phoenix and another for controlling the main camera of phoenix and taking care of squirrel for any possible accident. But with respect to using voice control and automatic function of Squirrel and after final process on controlling system and user interface, a trained operator might be able to control all the system.

The operator should be in a proper physical condition to be able to transport the equipment package (20-30 Kg).

Switching on the robots and running up the systems is simples and the interface is programmed user friendly, so no special training for the operator is needed.

Our team training consists of two parts:

1- Test robots in a situation similar to the competitions such as rubbles, steps and ramps which is shown in attached video files.

2- Determining, training and improving team strategy for the competitions in order to minimize the time of exploration, optimize the function of robots during the competition and real disaster situation and also modify and train ways in which robots can cooperate.

11. Possibility for Practical Application to Real Disaster Site

Real disaster situation was considered in all stages of designing. Mechanical properties of Phoenix allow it to traverse uneven paths (for example rubbles), ramps and steps and etc. the bodies of these two robots are firm enough to be able to resist against environmental condition during real disaster operation. Phoenix can be assembled and disassembled easily so for facilitating the transmissions to real disaster sites, it can be disassembled and then be reassembled even by an untrained operator.

Their electrical equipments and systems have been chosen such that the effects of the environment such as noises, impacts and etc on them are minimized. Also the ability of communication between the victim and the operator through a microphone and a speaker is considered. The robots will return the traversed path in case of disconnection of the communication from the server. In unstable and/or harmful conditions that can halt robots progress, the controlling system will send an alarm to the operator and/or make proper decision itself.

The interface software is user friendly so an untrained operator might be able of controlling the system.

The squirrel can start the exploration and check the safety of the path for traversing the Phoenix due to its small size and low weight; it can offer a more general view of the Phoenix to the operator if needed and also by using two robots, the connection area will be expanded.

A special place for an optional tool box in which the proper tools (due to the condition of the site will be placed) and 2 X-chairs are considered in the knapsacks.

We've planned to find a method for identifying the victim under the rubbles in future to apply it for gaining more capability in real disaster.

By considering the robots properties, we've found that the robots can be water-proof and fire-resistant by exerting a few changes on their components.

Also we have the idea of adding the ability of recognizing the safety of the environment for human presence with respect to factors like smoke, poisonous gas, flame and etc.

12. System Cost

Total cost and each part's cost of two robots are listed below:

TOTAL SYSTEM COST (Phoenix robot): 4100$

KEY PART NAME:	industrial computer (256MB RAM & 512 MB CF SSD)
PART NUMBER:	SBC82600
MANUFACTURER:	Axiomtek
COST:	600$
WEBSITE:	www.axiomtek.com.tw
DESCRIPTION/TIPS:	------

KEY PART NAME: PCI I/O card
PART NUMBER: DASP-52286
MANUFACTURER: Axiomtek
COST: 200$
WEBSITE: www.axiomtek.com.tw
DESCRIPTION/TIPS: this card is used to make link between software and hardware of the robot.

KEY PART NAME: Wireless PCI adapter
PART NUMBER: 3CRDAG675
MANUFACTURER: 3com
COST: 88$
WEBSITE: www.3com.com
DESCRIPTION/TIPS: ------

KEY PART NAME: Video capture card
PART NUMBER: GV-600
MANUFACTURER: Geovision
COST: 315$
WEBSITE: www.geovision.com.tw
DESCRIPTION/TIPS: ------

KEY PART NAME: Gyro sensor * 2
PART NUMBER: EN-03M
MANUFACTURER: Murata
COST: 40$
WEBSITE: www.murata.com
DESCRIPTION/TIPS: This sensor is to detect direction of the robot when moving on a ramp or climbing a step.

KEY PART NAME: Analog compass sensor
PART NUMBER: R1655
MANUFACTURER: The Robson Company (dinsmore sensor div)
COST: 37$
WEBSITE: www.dinsmoresensors.com
DESCRIPTION/TIPS: -----

KEY PART NAME: Non-contact IR thermometer
PART NUMBER: MID
MANUFACTURER: Raytek
COST: 200$
WEBSITE: www.raytek.com
DESCRIPTION/TIPS: This sensor is used to find victims and also to determine their body temperature.

KEY PART NAME: T video grabber + speech recognizer

PART NUMBER: -------
MANUFACTURER: Data stead
COST: 770$
WEBSITE: www.datastead.com
DESCRIPTION/TIPS: This software is used to send frames of image through the wireless network

KEY PART NAME: Main motors and gear head plus encoders
PART NUMBER: 118798+203129+228452
MANUFACTURER: Maxon motor
COST: 910$
WEBSITE: www.maxonmotor.com
DESCRIPTION/TIPS: -------------

KEY PART NAME: other mechanical components
PART NUMBER:
MANUFACTURER: local manufacturers
COST: 800$
WEBSITE: -------
DESCRIPTION/TIPS: all parts manufacturing costs are included

KEY PART NAME: ultra sonic and infra red sensors
PART NUMBER: -----------
MANUFACTURER: -----------
COST: 150$
WEBSITE: ------
DESCRIPTION/TIPS: ------

TOTAL SYSTEM COST (Squirrel robot): 1000$

KEY PART NAME: industrial computer (256MB RAM & 512 MB CF SSD)
PART NUMBER: SBC83680
MANUFACTURER: Axiomtek
COST: 400$
WEBSITE: www.axiomtek.com.tw
DESCRIPTION/TIPS: ----

KEY PART NAME: Wireless PCI adapter
PART NUMBER: 3CRDAG675
MANUFACTURER: 3com
COST: 88$
WEBSITE: www.3com.com
DESCRIPTION/TIPS: ------

KEY PART NAME:	Analog compass sensor
PART NUMBER:	R1655
MANUFACTURER:	The Robson Company (dinsmore sensor div)
COST:	37$
WEBSITE:	www.dinsmoresensors.com
DESCRIPTION/TIPS:	-----

KEY PART NAME:	other costs
PART NUMBER:	-----
MANUFACTURER:	-----
COST:	450$
WEBSITE:	-----
DESCRIPTION/TIPS:	mechanical components, encoders, and sensors included.

References

[1] Anh Tuan Le, Modeling and Control of Tracked Vehicles, department of mechanical and mechatronic Engineering, The University of Sydney

[2] CONTI SYNCHROBELT® Syncronous Drive Belts

[3] Gregory Dudek, Michael Jenkin , Computational Principles of Mobile Robotics , CAMBRIDGE UNIVERSITY PRESS

[4] J.E.Shigley, Mechanical Engineering Design 7th edition, Mc Graw Hill

[5] J.E.Shigley , Handbook of Mechanical Engineering

[6] Bill Drury, The Control Techniques Drives and Controls Handbook,The Institutin of Electrical Engineers, London.

[7] http://www.sao.ru/hq/sts/docs/sensors/clark/sens.html

[8] Robert L. Norton, Design of Machinery: An Introduction to Synthesis and Analysis of Mechanisms and Machines, Mc Graw Hill

Appendix

The design approach was such that first we assumed the probable obstacles (or combination of some of them) that the robot might encounter them. Then we determined some simplified and regular shapes having similar feature as the "Standard Obstacles". Finally we arranged them with respect to their difficulty and importance. Passing all these steps and examining different types of locomotion systems we decided on the mentioned locomotion system.

It should be noted that some of these obstacles were arranged to be necessarily traversed by the designed robot. Also if a design provides the ability to pass the others it will be more preferable.

The results of this standardizing are as follows: